10-11 An ideal vapor-compression refrigeration cycle with refrigerant-134a as the working fluid is considered. The rate of heat removal from the refrigerated space, the power input to the compressor, the rate of heat rejection to the environment, and the COP are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

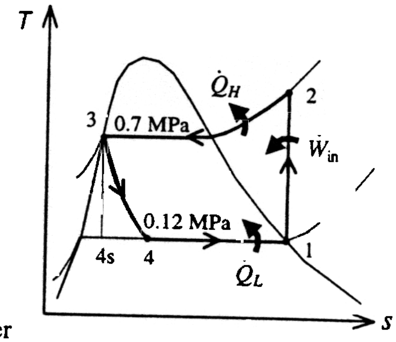
Analysis (*a*) In an ideal vapor-compression refrigeration cycle, the compression process is isentropic, the refrigerant enters the compressor as a saturated vapor at the evaporator pressure, and leaves the condenser as saturated liquid at the condenser pressure. From the refrigerant tables (Tables A-12 and A-13),

$$\left.\begin{array}{l} P_1 = 120 \text{ kPa} \\ \text{sat.vapor} \end{array}\right\} \begin{array}{l} h_1 = h_{g\ @\ 120\ \text{kPa}} = 233.86 \text{ kJ/kg} \\ s_1 = s_{g\ @\ 120\ \text{kPa}} = 0.9354 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 0.7 \text{ MPa} \\ s_2 = s_1 \end{array}\right\} h_2 = 270.22 \text{ kJ/kg } (T_2 = 34.6°\text{C})$$

$$\left.\begin{array}{l} P_3 = 0.7 \text{ MPa} \\ \text{sat.liquid} \end{array}\right\} h_3 = h_{f\ @\ 0.7\ \text{MPa}} = 86.78 \text{ kJ/kg}$$

$$h_4 \cong h_3 = 86.78 \text{ kJ/kg (throttling)}$$



Then the rate of heat removal from the refrigerated space and the power input to the compressor are determined from

$$\dot{Q}_L = \dot{m}(h_1 - h_4) = (0.05 \text{ kg/s})(233.86 - 86.78) \text{ kJ/kg} = \mathbf{7.35\ kW}$$

and

$$\dot{W}_{in} = \dot{m}(h_2 - h_1) = (0.05 \text{ kg/s})(270.22 - 233.86) \text{ kJ/kg} = \mathbf{1.82\ kW}$$

(*b*) The rate of heat rejection to the environment is determined from

$$\dot{Q}_H = \dot{Q}_L + \dot{W}_{in} = 7.35 + 1.82 = \mathbf{9.17\ kW}$$

(*c*) The COP of the refrigerator is determined from its definition,

$$\text{COP}_R = \frac{\dot{Q}_L}{\dot{W}_{in}} = \frac{7.35 \text{ kW}}{1.82 \text{ kW}} = \mathbf{4.04}$$

10-14 [*Also solved by EES on enclosed CD*] An ideal vapor-compression refrigeration cycle with refrigerant-134a as the working fluid is considered. The quality of the refrigerant at the end of the throttling process, the COP, and the power input to the compressor are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible.

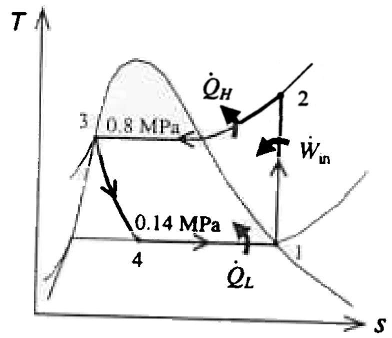
Analysis (*a*) In an ideal vapor-compression refrigeration cycle, the compression process is isentropic, the refrigerant enters the compressor as a saturated vapor at the evaporator pressure, and leaves the condenser as saturated liquid at the condenser pressure. From the refrigerant tables (Tables A-12 and A-13),

$$\left.\begin{array}{l} P_1 = 140 \text{ kPa} \\ \text{sat. vapor} \end{array}\right\} \begin{array}{l} h_1 = h_{g\ @\ 140\text{ kPa}} = 236.04 \text{ kJ/kg} \\ s_1 = s_{g\ @\ 140\text{ kPa}} = 0.9322 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 0.8 \text{ MPa} \\ s_2 = s_1 \end{array}\right\} h_2 = 272.05 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 0.8 \text{ MPa} \\ \text{sat. liquid} \end{array}\right\} h_3 = h_{f\ @\ 0.8\text{ MPa}} = 93.42 \text{ kJ/kg}$$

$$h_4 \cong h_3 = 93.42 \text{ kJ/kg (throttling)}$$



The quality of the refrigerant at the end of the throttling process is

$$x_4 = \left(\frac{h_4 - h_f}{h_{fg}}\right)_{@\ 140\text{ kPa}} = \frac{93.42 - 25.77}{210.27} = \mathbf{0.322}$$

(*b*) The COP of the refrigerator is determined from its definition,

$$\text{COP}_\text{R} = \frac{q_L}{w_\text{in}} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{236.04 - 93.42}{272.05 - 236.04} = \mathbf{3.96}$$

(*c*) The power input to the compressor is determined from

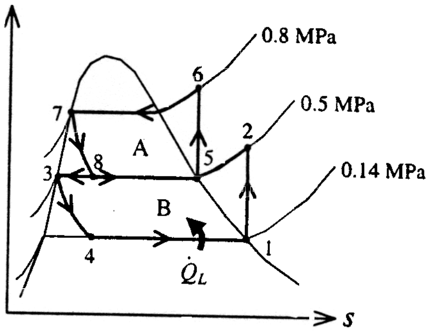
$$\dot{W}_\text{in} = \frac{\dot{Q}_L}{\text{COP}_\text{R}} = \frac{5 \text{ kW}}{3.96} = \mathbf{1.26\ kW}$$

10-39 A two-stage cascade refrigeration system is considered. Each stage operates on the ideal vapor-compression cycle with refrigerant-134a as the working fluid. The mass flow rate of refrigerant through the lower cycle, the rate of heat removal from the refrigerated space, the power input to the compressor, and the COP of this cascade refrigerator are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible. **3** The heat exchanger is adiabatic.

Analysis (*a*) Each stage of the cascade refrigeration cycle is said to operate on the ideal vapor compression refrigeration cycle. Thus the compression process is isentropic, and the refrigerant enters the compressor as a saturated vapor at the evaporator pressure. Also, the refrigerant leaves the condenser as a saturated liquid at the condenser pressure. The enthalpies of the refrigerant at all 8 states are determined from the refrigerant tables (Tables A-11, A-12, and A-13) to be

$$h_1 = 236.04 \text{ kJ/kg}, \quad h_2 = 262.07 \text{ kJ/kg}$$
$$h_3 = 71.33 \text{ kJ/kg}, \quad h_4 = 71.33 \text{ kJ/kg}$$
$$h_5 = 256.07 \text{ kJ/kg}, \quad h_6 = 265.72 \text{ kJ/kg}$$
$$h_7 = 93.42 \text{ kJ/kg}, \quad h_8 = 93.42 \text{ kJ/kg}$$



The mass flow rate of the refrigerant through the lower cycle is determined from an energy balance on the heat exchanger:

$$\dot{E}_{\text{in}} - \dot{E}_{\text{out}} = \Delta\dot{E}_{\text{system}}^{\not{0}\,\text{(steady)}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\sum \dot{m}_e h_e = \sum \dot{m}_i h_i$$

$$\dot{m}_A(h_5 - h_8) = \dot{m}_B(h_2 - h_3)$$

$$\dot{m}_B = \frac{h_5 - h_8}{h_2 - h_3}\dot{m}_A = \frac{256.07 - 93.42}{262.07 - 71.33}(0.24 \text{ kg/s}) = \mathbf{0.2047 \text{ kg/s}}$$

(*b*) The rate of heat removed by a cascade cycle is the rate of heat absorption in the evaporator of the lowest stage. The power input to a cascade cycle is the sum of the power inputs to all of the compressors:

$$\dot{Q}_L = \dot{m}_B(h_1 - h_4) = (0.2047 \text{ kg/s})(236.04 - 71.33) \text{ kJ/kg} = \mathbf{33.71 \text{ kW}}$$

$$\dot{W}_{\text{in}} = \dot{W}_{\text{compI,in}} + \dot{W}_{\text{compII,in}} = \dot{m}_A(h_6 - h_5) + \dot{m}_B(h_2 - h_1)$$
$$= (0.24 \text{ kg/s})(265.72 - 256.07) \text{ kJ/kg} + (0.2047 \text{ kg/s})(262.07 - 236.04) \text{ kJ/kg}$$
$$= \mathbf{7.64 \text{ kW}}$$

(*c*) The COP of this refrigeration system is determined from its definition,

$$\text{COP}_\text{R} = \frac{\dot{Q}_L}{\dot{W}_{\text{net,in}}} = \frac{33.71 \text{kW}}{7.64 \text{kW}} = \mathbf{4.41}$$